# AWE: Aviation Weather Data Visualization

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## Abstract

The two official sources for aviation weather reports both require the pilot to mentally visualize the provided information. In contrast, our system, Aviation Weather Environment (AWE) presents aviation specific weather available to pilots in an easy to visualize form. We start with a computer-generated textual briefing for a specific area. We map this briefing onto a grid specific to the pilot's route that includes only information relevant to his flight as defined by route, altitude, true airspeed, and proposed departure time. By modifying various parameters, the pilot can use AWE as a planning tool as well as a weather briefing tool.

## 1 Introduction

The National Weather Service (NWS) and the Federal Aviation Administration (FAA) gather and disseminate a great deal of weather information helpful to pilots. Weather observations both at the surface and aloft, real-time radar information, satellite observations, radiosonde balloons and forecasts prepared by meteorologists are packaged and disseminated to pilots at least once per hour. Pilots have two primary sources for official weather reports: Flight Service Station (FSS) specialists[1] and the DUATs (Direct User Access Terminal)[2] computer system. FSS specialists can be reached via telephone, aircraft radio, or infrequently, in person. In any case, the briefing is verbal and the pilot is responsible for mentally visualizing the provided information. DUATS computer briefings are textual and also require the pilot to mentally visualize the "big picture." Pilots often supplement these official briefings with graphics available from the Weather Channel or unofficial weather web sites. Because this supplemental information is not geared toward aviation applications, however, it is often difficult to extract necessary information easily.

Weather is one of the major causes of aviation accidents. Continued flight into worsening conditions (with the optimistic hope for improvement) is one of the leading causes of loss of control for general aviation flights. Improvements in technology (primarily data link) promise to bring much needed information directly to the in-flight pilot [1]. However, data link proponents are still considering providing much of the information in a textual format. With the duties required by single-pilot operations, this information will need to be presented in a cognitively easy to decipher format if it is to provide optimal help.

Our system, the Aviation Weather Environment, AWE, proposes one solution to this problem. In its ultimate configuration, it will provide an intelligent interface to weather data for the in-flight pilot. The pilot will be able to quickly determine current and forecast conditions along his planned route, get help determining alternate routes or alternate destinations, and get automatic warnings of worsening conditions. Either the pilot or an intelligent agent acting on his behalf can explore "what-if" scenarios to determine optimal

plans. Data link technologies will be exploited to get current weather from ground facilities as well as other airborne aircraft.

Because this technology is still under development, our initial system provides the pilot with a cognitively easy to decipher format for DUATs briefings. We start with a DUATs briefing for a specific area, for example, a 95 nautical mile (nm) radius from the Palo Alto airport, KPAO. We map this briefing onto a grid specific to the pilot's route that includes only information relevant to his flight as defined by route, altitude, true airspeed, and proposed departure time. The pilot is able to visualize current area weather, forecast area weather, or route specific weather. For route specific weather, rather than displaying current data available for his destination, we use forecasts available for his proposed time of arrival. By modifying various parameters, the pilot can also use AWE as a planning tool.

## 2 Previous Work

Before the consolidation of Flight Service Stations, pilots were able to physically visit with an FSS specialist. Specialists have access to charts that graphically display current conditions and a limited set of forecasts [4]. These include the following charts: surface analysis chart, weather depiction chart, radar summary chart, significant weather prognosis chart, winds and temperatures aloft chart, composite moisture chart, severe weather outlook chart, constant pressure analysis chart, and tropopause data chart. A great deal of information is available to a pilot [3]; so much in fact that most pilots do not know how to read most of these charts, nor how to interpret what the data is telling them. Hence the need for FSS specialists.

A number of web sites have recently been created which attempt to provide information similar to that provided by the FSS charts described above [6, 2, 5]. They typically display weather for the entire U.S., but do not allow the pilot to zoom into a region of interest, such as along his route. Also, as in the FSS charts, the information is distributed through multiple charts. Integration of the information is still performed by the pilot.

DUATs compresses much of this data and packages it very differently in an attempt to make it easier to understand for the pilots. However, it is based on old teletype technology and is cryptic to read. A textual DUATs area briefing provides:

- Area Forecast including position of fronts, pressure systems, wind conditions, cloud layers, weather (such as rain), and an outlook stating whether conditions will be IFR, MVFR, and VFR [3].

- Severe Weather Warnings

- SIGMETs[4] and Convective SIGMETs[5]

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[1]FSS specialists are FAA employees.
[2]DUATs is offered by private companies under contract to the FAA.

[3]IFR = Instrument Flight Rules: visibility <= 3 miles and/or ceiling <= 1000 feet; MVFR = Marginal VFR: visibility <= 5 miles and ceiling <= 3000 feet; and VFR = Visual Flight Rules: visibility > 5 miles and ceiling > 3000 feet.
[4]Significant Meteorological Conditions
[5]Example: thunderstorms

- AIRMETs[6] for turbulence, mountain obscuration, widespread IFR conditions, and icing conditions and freezing levels.

- Surface Observations (METARs[7]) of current conditions, including ceilings, visibility, wind, barometric pressure, temperature and dew points for certain airports.

- Pilot Reports

- Radar Summaries that textually provide information about echos, echo movement, and echo intensity.

- Terminal Forecasts (TAFs[8]), including ceiling, visibility, and wind forecasts for certain airports.

- Winds Aloft Forecasts for relevant sites at altitudes of 3000 feet to 39000 feet, by 3000 foot increments.

# 3  AWE Approach

AWE presents a new method of interacting with aviation weather. It can be used either as a briefing tool or as a planning tool. We begin with an area briefing from the FAA-approved DUATs aviation briefing service. We then present a subset of the provided information graphically. The subset is selected to augment current techniques for visualizing various information. The use of satellite images to display clouds, radar echos to display precipitation, and contour lines to display temperatures are well known and quite effective. The display of winds as arrows is also currently used effectively. We concentrate on displaying aviation specific weather that is not currently displayed effectively. In particular, AWE displays current weather observations, known as METARs, and weather forecasts, known as TAFs. Although the display of wind direction and speed has been explored previously, AWE also displays winds aloft data because we find it integrates well with METARs and TAFs and is very useful to the pilot for planning purposes.

AWE provides the pilot options to display area-wide or route-specific winds aloft, current METAR observations, and TAF forecasts. AWE uses standard visualization techniques such as color coded icons to present the information in an easy to decipher display format.

AWE allows the user to specify his flight including route, desired altitude, true airspeed, and proposed departure time; select whether he wants to see current weather or forecast weather; and select whether the area of interest is just the route or area-wide. The user is able to modify any of the route parameters and see the effect on weather he might encounter.

Additional underlying capability is required to visualize a DUATs briefing. This includes providing AWE information about airports[9], parsing the briefing, and translating it into a computer-understandable version. We discuss each of these issues in the following sections.

## 3.1  AWE Foundation

AWE is written using C++, OpenGL, and Xforms and runs on an SGI workstation. The underlying capability, or AWE's foundation, consists of object-oriented programming classes that deal with information about airports, METAR, TAF, and winds aloft. It also includes supporting classes that know how to deal with latitude and

longitude coordinates and can find distances between lat/long locations. Four data files are used by AWE. Airport identifiers as well as the latitude and longitude coordinates of the airport are specified in a user readable data file, and the DUATs briefing is translated into three separate files: one containing current METARs, one containing TAF forecasts, and one containing winds aloft forecasts.

The winds aloft forecast is transferred directly with little modification. The class that deals with winds aloft contains methods for retrieving the obvious elements. We also provide a means of finding the freezing level (defined as the level at which the temperature is 0 degrees Celsius). Finally, we provide a method for forecasting the winds aloft at an arbitrary lat/long location. DUATs only provides winds aloft for certain locations and for certain altitudes. We use distance-based interpolation to determine the winds at the specified lat/long location.

Because our emphasis is on visualization and not parsing, the METARs and TAFs are somewhat simplified. Additional parsing capability will be needed to deal with more of the information DUATs provides. The major simplification we implemented was for cloud layers. DUATs briefings provide multiple layers of clouds, when applicable; we restrict the cloud layers to a single representative layer, chosen based on a priority level. Broken "BKN" or overcast "OVC" layers are given the highest priority, and thus the lowest layer of that type is chosen as the representative. Scattered "SCT" layers are given the next priority level, followed by "FEW", and finally none, or "CLR" (for clear). Thus, the representative is the worst the pilot can expect to encounter. Both METARs and TAFs implement a similar cloud layer scheme. Another much less limiting simplification is deleting input format comments associated with METARs.

The two final foundation classes are Awe_interface and Awe. Awe_interface deals with interactions with the user, properly updating the input forms. The Awe class maintains a list of known airports, and reads and updates winds aloft, METAR, and TAF reports. It also provides various search methods, such as finding the closest airport to an arbitrary lat/long position; getting the METAR/TAF for an airport with reporting capability; getting a representative METAR/TAF for non-reporting airports; finding the closest and second closest winds aloft forecasts; or keeping track of the user's chosen route. Each of these methods is used by other foundation classes to help provide what the user wants.

## 3.2  Graphical Interface and Display

The graphics portion of AWE relies on the foundation classes to compute what information to display. We will now discuss *how* we display it. We begin by texturing the background AWE window with our local area of the San Francisco Sectional Aeronautical chart to give pilots a familiar environment with which to interact. The chart shows the location of airports, navigation aids, controlled and special (such as restricted) airspaces, obstructions, natural terrain features (such as water and hills, depicted using color coded altitudes), and congested areas (such as cities, depicted in yellow).

### Defining the Flight

The pilot specifies his route of flight by selecting (with the mouse) a sequence of airports.[10] The user is able to extend his route by adding an airport to the end, modify his route by deleting airports off the end until the modification point is reached (eventually backtracking to the beginning if desired), or specifying a new route. As airports are added or deleted, the interface is updated to reflect the current specified route. The background screen with a route selected by the pilot is shown in Figure 2.

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[6] Airman's Meteorological Information

[7] METAR is an acronym for Meteorological Observation.

[8] TAF is an acronym for Terminal Area Forecast.

[9] Locations of navigation aids, like VORs (VHF OmniRange), would also be useful and can easily be added to AWE.

[10] As stated earlier, AWE does not currently recognize navigation aids such as VORs.

Using sliders, the pilot is able to select his flight altitude and the aircraft's true airspeed. The pilot is also given an input window in which to specify his proposed departure time. These selections are used to determine what specific information to display, as discussed below.

## Selecting Information Overlays

A full version of AWE would provide options to overlay all the information a pilot may want to view. This includes satellite images, temperature contours, etc. Because much of that data is already effectively visualized by other sources, we simplified AWE to restrict his options to a limited set of combinations. His options are limited to:

- Display focus: area wide weather vs. route specific weather;

- Type of weather: current weather observations (METAR) vs. forecast weather (TAF), and/or winds aloft;

- Display options: show closest available weather and/or show textual or iconic view.

*Display Focus:* The pilot can choose to display weather either just along his route of flight or for the entire area known by AWE. The area wide weather option is especially useful during the planning phase. The pilot can view all available weather and then choose a route of flight. Conversely, if he has already chosen a destination, route specific weather shows him only information relevant to his flight.

*Type of Weather:* The pilot can choose to view either current (METAR) or forecast (TAF) weather, as well as winds aloft information. Most (possibly all) airports that provide TAF forecasts also provide METAR observations. Therefore, we implemented the options to display METARs or to display TAFs to be mutually exclusive; that is, either METARs or TAFs can be displayed, but not both simultaneously. Winds aloft, on the other hand, provide not both simultaneously. Winds aloft, on the other hand, provide complementary information to both sources and can be displayed either alone or with a TAF or METAR. METARs and TAFs provide surface winds associated with the reporting airport. Winds aloft provide winds at various altitudes and are associated with a much wider area around the airport.

*Display Option: Use closest:* Not all airports AWE knows about have weather reporting capabilities. If the pilot is viewing route specific weather, we provide him with the option of choosing to display the nearest report (of the same type) for airports that fit this criteria. To accomplish this, the pilot chooses the "show closest available weather" option.

*Display Option: Show Icons:* One disadvantage of displaying all available METAR or TAF information is the amount of screen space it occupies. This is typically not a major problem for TAFs since only a few airports provide that service. Congested areas with many local airports do not fare as well with METARs. As an example, the San Francisco Bay Area has eight airports that issue METARs in the small area surrounding the bay. Thus, if the display option is area-METARs, the advantage of providing all information may quickly turn into a problem, with METARs hiding each other. In this situation, the pilot can still extract information provided by the IFR/MVFR/VFR border coding scheme discussed below. He can quickly determine the type of conditions dominating the area. He can also select the "route-METAR" display option and select airports individually to see the particulars.

AWE provides an option to attenuate the clutter. For either TAF or METAR displays, the pilot can choose to display the information using coded icons rather than text, as shown in Figure 3 and discussed below. The icon display provides only enough information to give the pilot a general idea of the weather conditions. Details are available only when he deselects the "show icons" option.

*Time-dependent Information:* Pilots need the forecast weather at the time of arrival at each en-route checkpoint (airport, in AWE), not the forecast for the departure time. To eliminate the need for the pilot to specify a full flight plan with expected arrival times, we calculate arrival times automatically based on the specified true airspeed and departure time. If the pilot is looking at route-specific TAFs, he will be given the appropriate forecast based on this information.

*Choosing Appropriate Forecast:* Determining the appropriate forecast is not as simple for a computer as it is for a person. DU-ATs forecasts are not specified as mutually exclusive time ranges. Rather, the general forecast (given first) covers a 24 hour period. Forecasts for more specific times are then given. Even these specific time periods can overlap. For example, in a TAF file for the KSCK (Stockton airport), we find that three forecasts may apply for 10:30. First, the general one that spans the range 18:00 on the 18th of the month to 18:00 on the 19th states that the weather will be {wind 300@6, plus 6 statute mile (sm) visibility, sky clear}. Then, the "FM1000", states that from 10:00, the weather will be {wind calm, visibility of 1 sm with mist, sky clear}. Finally, the "TEMPO 1015" states that there will be a temporary condition from 10:00 to 15:00 of weather {1/4 sm visibility with fog, and a vertical visibility of 200 feet}. AWE must determine which one of these to present to the user. AWE chooses to present the worst scenario. Thus, in this case, it chooses the temporary condition as the representative weather.

## Displaying Information Overlays

We now turn to the display formats.

*Winds Aloft Display:* Displaying wind information is straightforward. We rotate the wind arrow to show the direction of the wind at that location and display the wind speed alongside. If the pilot has requested area wide weather, AWE displays all known winds aloft forecasts for central California. If the pilot requests route weather, on the other hand, we display wind information alongside each airport along his route, interpolated as described before and illustrated in Figure 2. Displaying winds aloft graphically allows the user to quickly compare his flight path to the path of the wind and determine whether to expect a tailwind, headwind, or crosswind. It helps his situational awareness by giving him a direct picture of expected conditions. He can then compensate for a crosswind without much thought, or expect to go slower and use more fuel for a strong headwind. Because winds aloft are altitude dependent, the pilot can modify his selected altitude to determine where the winds are most favorable. The display is updated in real time to reflect his selection.

*Textual METAR/TAF Display:* Determining how to display a METAR or a TAF to make it easily decipherable yet provide all the necessary information is more complicated. The FAA approach, used with charts available at Flight Service Stations, are very informative, yet very cryptic. Their symbols, shown in Figure 1, require memorization and can be easily forgotten if not used regularly. Instead, we could choose to follow the Weather Channel approach and display only a small set of symbols. One disadvantage of this approach is that much of the available information is not represented.

We chose to provide the pilot with all the information available. The pilot has the option to ask for all information textually attached next to the airport or for only an iconic view that provides him with a "feel" for the weather, but no specifics. A textual display of METAR information is shown in Figure 2. An iconic representation is similar to the TAF icons shown in Figure 3.

To make the task of recognizing conditions quicker, we represent the wind direction graphically (similar to the winds aloft display) as well as textually. The pilot can now easily compare the wind

| Symbol | Meaning | Symbol | Meaning |
|--------|---------|--------|---------|
| ⌒ | Moderate turbulence | ▽ | Rain shower |
| ⌒ | Severe turbulence | ▽ | Snow shower |
| ⱂ | Moderate icing | ⌇ | Thunderstorms |
| ⱂ | Severe icing | ⌒ | Freezing rain |
| ● | Rain | 6 | Tropical storm |
| ✳ | Snow | 6 | Hurricane (typhoon) |
| 9 | Drizzle | | |

Figure 1: FAA weather symbols.

direction with the orientation of the runways as displayed on the sectional (AWE's background image). Thus, crosswind landing conditions become visually obvious.

The textual displays are supplemented with color-coded borders to warn the pilot of possible adverse conditions. Recall that IFR, Instrument Flight Rules, apply when the visibility is <= 3 miles or the ceiling[11] is <= 1000 feet. Many pilots are prevented either legally (by not having appropriate certification) or practically (by not being proficient) from landing at airports with IFR conditions. MVFR conditions are only a practical, not a legal, determent (many pilots feel less safe in marginal conditions). AWE displays airports with IFR conditions with a red border, airports with MVFR with a yellow border, and those with VFR without a border. The pilot can thus easily see where the widespread areas of low visibility or low ceilings are located. A sample "route-METAR" display is shown in Figure 2.

*Iconic METAR/TAF Display:* There are four primary elements that affect a pilot's "go / no go" decision: wind conditions, visibility, cloud altitude, and temperature / dew point spread. Wind shear, turbulence, and strong crosswinds are possibilities under high wind conditions. Temperature and dew point can be important in certain conditions. For instance, in the SF bay area, morning and evening fog is often a consideration. The temperature / dew point spread then becomes valuable information. If the airport is currently experiencing fog, the spread gives information on when it may clear (especially if you have the previous hour's METAR and can see a trend in how the spread is changing). Similarly, in the heat of the summer, temperature is very important at high altitude airports since it has a direct effect on aircraft takeoff characteristics. And, though the author does not have much experience with cold weather, very low temperatures also have an effect, not on takeoff but on engine start. They can also contribute to possible ice on the airframe. Usually, though, temperature can be safely classified as non-critical information and is not represented in the iconic format. Just as in the definition of IFR, MVFR, and VFR conditions, visibilities and cloud conditions are probably considered the most important elements.

Our icons are designed to present a quick overview of the four primary elements. The icon is a triangle (modeled after warning triangles) that is subdivided into four triangles, each representing one of the important elements. The wind triangle is shown in white if the wind speed is less than 15 knots, yellow if it's between 15

kts. and 20 kts., and red if it exceeds 20 kts. The visibility triangle is shown in white if the visibility is greater than 5 nm, yellow if it's is between 3 and 5 nm, and red if it's is less than or equal to 3 nm. The cloud altitude triangle is shown in white if the lowest ceiling layer is greater than 3000 feet, yellow if it's above 1000 and below 3000 feet, and red if it's at or below 1000 feet. Finally, the temperature / dew point spread triangle is shown in white if the spread is greater than 4.5 degrees Celsius, yellow if it's between 2 and 4.5 degrees, and red if it's below 2 degrees. Because TAFs do not provide temperature or dew point forecasts, the TAF icon consists of just three triangles. The temperature / dew point spread triangle is always shown in gray. In each of these cases, the color coding serves only to alert the pilot of possible adverse conditions. The thresholds were chosen to coincide with the FAA definitions of IFR and MVFR conditions for visibility and ceiling. The wind speeds and temperature dew point spreads were chosen based on a typical pilot and weather profile.

## 4  AWE Advantages

We have already mentioned several advantages of AWE. A not immediately apparent advantage is for non-local pilots. Local pilots know the identifiers for most, if not all, the airports within 100 miles. They can immediately picture where the airport is, how far it is from their home airport, and what their flight path would look like. Non-local pilots, on the other hand, have a more difficult time interpreting a DUATs area briefing. They must refer to the chart or other reference material to determine which airport an identifier refers to, to visualize where airports are located, to determine which airport is closest to one without a TAF, etc. All that information is directly available on AWE. They can now visualize the weather as easily in a distant area as they can in their local area.

One of the other useful aspects of AWE is its use as a planning tool. AWE allows the pilot to specify his airplane's true airspeed, to select an altitude, and to select a departure time. Any of these can be modified during the AWE session; METARs, TAFs, and winds aloft are updated immediately to reflect the new selections. Thus, the pilot can choose a favorable altitude (e.g., with more tailwinds), choose to slow down and save fuel if the winds will let him arrive within a time window of his choice, or choose to depart earlier or later to use the forecast to his advantage. The recreational pilot can even use AWE to decide on a direction for his pleasure flight. The combination of these features makes AWE a very useful tool for local and non-local pilots alike.

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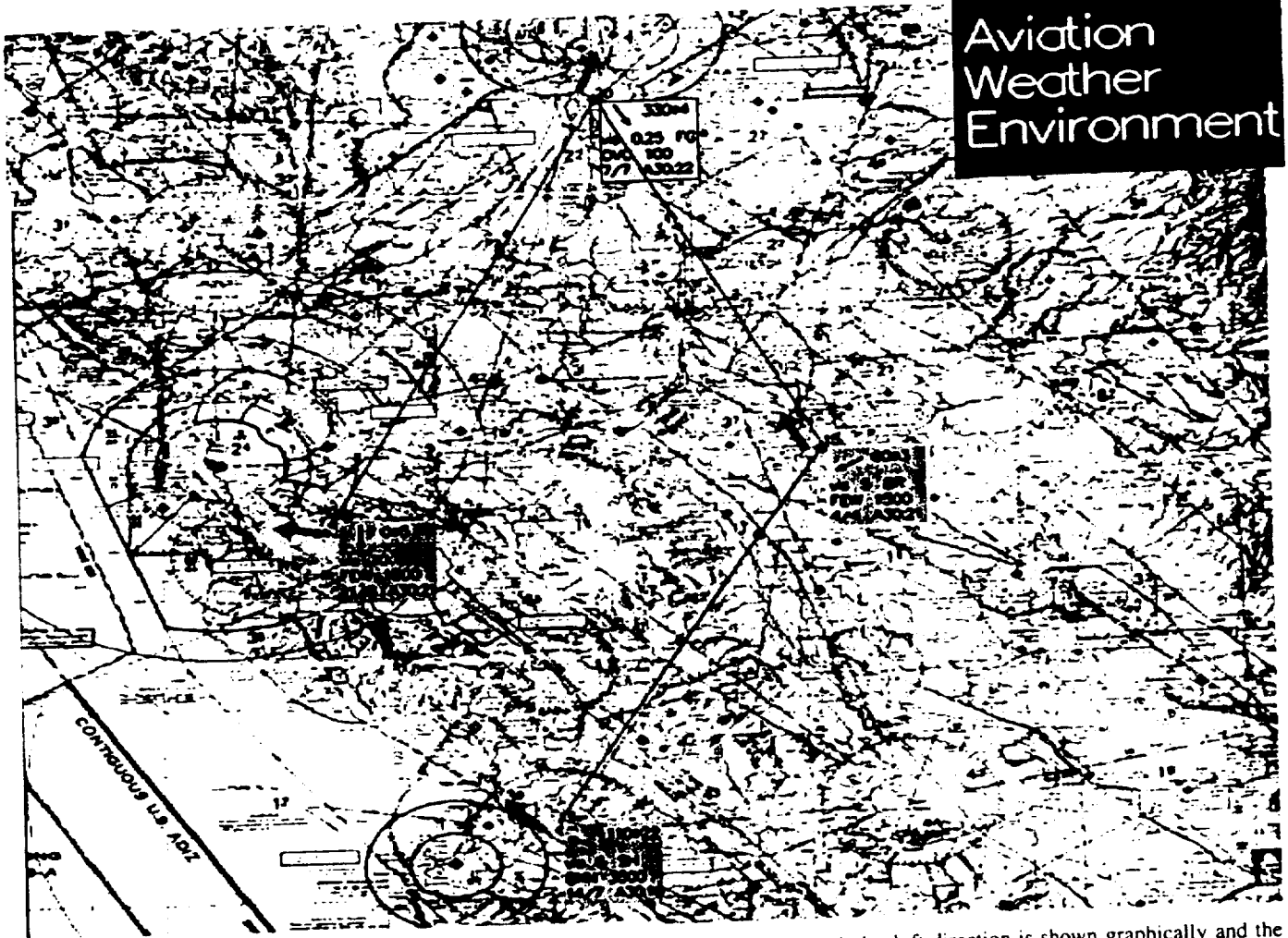[11]Ceiling is defined as a broken (BKN) or overcast (OVC) layer.

Figure 2: Route METARs and winds aloft shown alongside a pilot-selected route. The winds aloft direction is shown graphically and the wind speed is shown textually. Within the METAR box, surface winds are shown graphically as well as textually. Visibility, cloud altitude, temperature and dew point are only shown textually. The METAR box border depicts instrument flight conditions (red border), marginal visual flight conditions (yellow border), or visual conditions (no border).
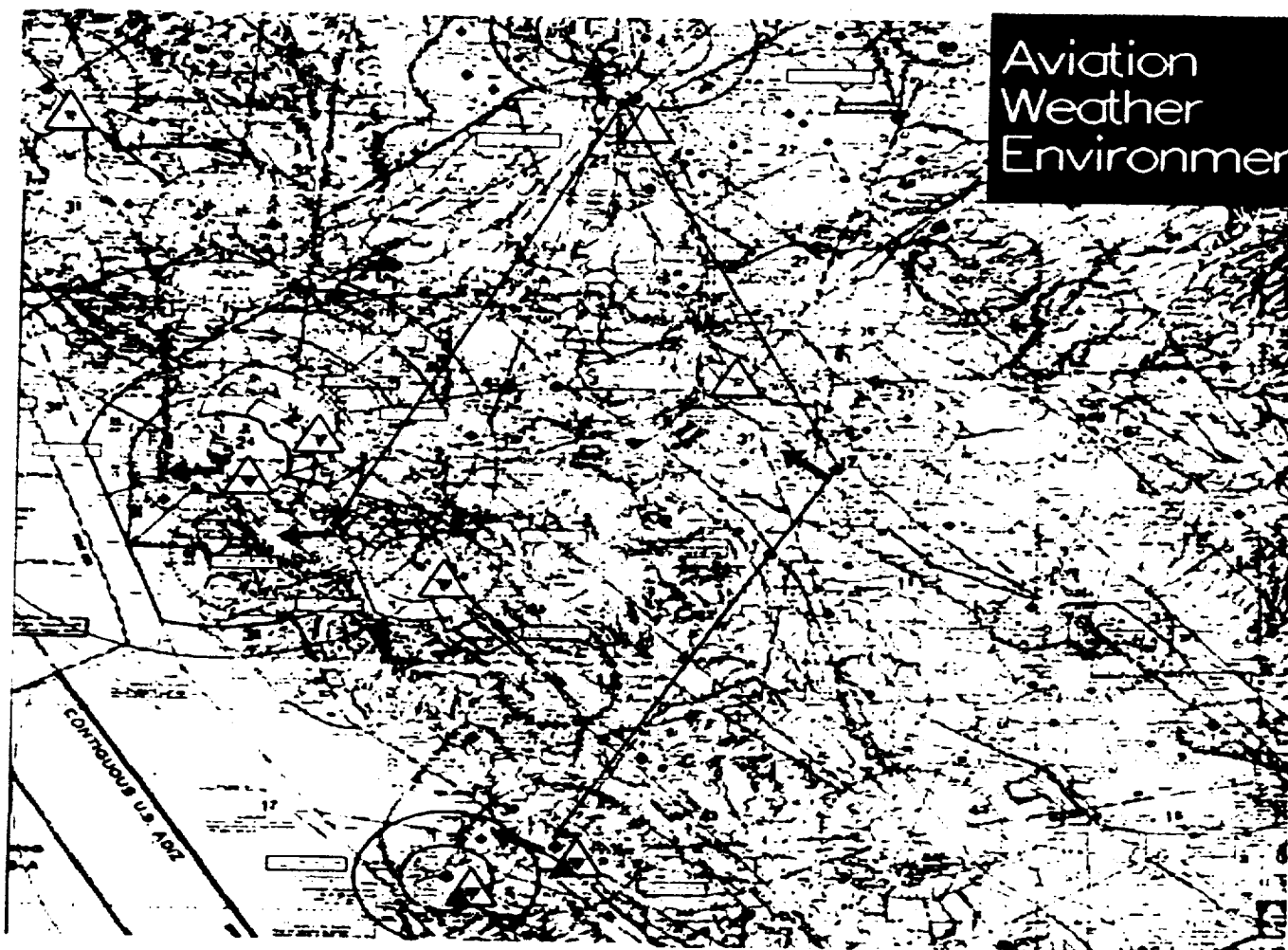
**Figure 3:** Area TAF display using triangular icons. The color in each of the four subtriangles indicate adverse, marginal, or safe conditions. The upper subtriangle depicts wind conditions; the middle subtriangle depicts temperature/dew point spread; the lower left subtriangle depicts cloud altitudes; and the lower right subtriangle depicts visibility conditions.